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ABSTRACT

A Venus meteorological balloon system for a 1977 manned triple planet flyby opportunity is conceptually designed to a level of detail sufficient to establish its feasibility. The system objectives are to determine the gross wind circulation patterns at various altitudes in the Venus atmosphere by tracking from an overflying orbiter and to acquire a variety of Venus atmospheric data by information relay using the orbiter probe.

For each of the two Venus encounters of the mission opportunity the system consists of two identical probes each delivering six superpressure balloons to two widely separated target areas of the atmosphere. In each location the six balloons are deployed at 5, 10, 25, 30, 40 and 45 km altitudes. The twelve balloons have design lifetimes of approximately one month and a maximum possible data return of about 2.3×10^6 bits of atmospheric data. The estimated gross probe weight at separation from the manned vehicle is about 1800 pounds. The orbiter is covered only to the extent of its communications subsystem interface with the balloons.

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TECHNICAL MEMORANDUM

I. INTRODUCTION

This memorandum describes a meteorological balloon system which could be deployed at selected altitudes in the Cytherean atmosphere during the two Venus encounter portions of a 1977 manned triple planet flyby mission.[1] The system objectives in order of priority are: (1) to provide information on the gross atmospheric circulation patterns of Venus by tracking from an overflying orbiter probe; and (2) to obtain from the balloon sensor payload data on atmospheric temperature, pressure, humidity, local turbulence and local electrical activity as a function of altitude and surface spatial location. The information acquired by achievement of the two objectives will be used to partially resolve the substantial uncertainties in knowledge of the Venusian atmosphere as well as provide design data for possible subsequent buoyant Venus laboratories. Because of the uncertainty in regard to the atmosphere and the desire for a reasonable probability of mission success, the primary design philosophy for the balloon instrument payload and supporting subsystems is to emphasize ruggedness and simplicity rather than extensive capability.

Our present knowledge of the Cytherean atmospheric circulation is confined to observations in the U.V. of cloud motion in the upper atmosphere.[2] These observations suggest that at this level the "air" moves in the direction of planetary rotation with velocities in excess of 300 km/hr. The bulk of the atmosphere, however, lies beneath the clouds and it is thought that an entirely different circulation regime is maintained there. For a slowly rotating planet like Venus, having essentially unilateral insolation, it is expected that the gross "air" movement will take place between the sub-solar and anti-solar points. Goody and Robinson have suggested that the motion will generally take the form of a slow large-scale overturning.[3]

Under the mission concept expressed in Reference 1 a total of twelve balloons are deployed in the atmosphere during each of the two Venus encounter portions of the mission. Also during each encounter an orbiter probe is deboosted into a 4000 km circular orbit whose plane is appropriately oriented for tracking, data reception and relay operations in conjunction with the balloons. The conceptual design of the balloons and their delivery system is presented herein while the orbiter probe is covered in a separate study.[4] The balloon delivery system for Venus encounter consists of two probes each carrying six balloons and targeted for different localities consistent with orbiter probe communications and tracking area coverage constraints. The weight of each probe at separation from the manned vehicle is estimated at 1800 pounds. Thus, for the 1977 triple planet flyby mission the total balloon system weight at earth departure, excluding the two orbiter probes, is about 7200 pounds.

It is beyond the scope of this memorandum to include a consideration of alternative methods of investigating the circulation of the Cytherean atmosphere. However, it should be made clear that there is no a priori reason why the balloons could not be delivered in an unmanned mission mode provided there is suitable upgrading of the probe subsystems to accommodate the increased flight time. The feasibility of such a mission and the possibility of tracking the balloons from Earth would be interesting subjects for future study.*

In the following discussion the conceptual design and operation of the meteorological balloon system are described in terms of its mission profile, payload subsystem and support subsystems.

II. MISSION PROFILE

The probe mission profile is presented graphically in Figures 1A and 1B. Figure 1A covers the profile from separation to entry while Figure 1B illustrates the terminal velocity phase during which the balloons are deployed.

Probe separation from the manned vehicle occurs at about -5 days.** After the sterilization canister is jettisoned, the application of a velocity change of about 600 ft/sec provides for probe entry at -3 hours. Additional velocity change capability

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*An interferometer technique might be used to track the balloons from Earth with useful accuracy.[5] Direct data transmission from Venus to Earth would, however, imply substantial changes in the balloon subsystems.

**Referred to time of manned vehicle periapsis.

of 150 ft/sec is provided for a midcourse correction to be performed at -2.5 days. Probe tracking and computation of the midcourse correction is performed onboard the manned vehicle. At -4 hours all delivery subsystems except the entry shell are jettisoned and at -3 hours probe entry into the atmosphere occurs. The design entry conditions are as follows:

Entry Path Angle (EPA) $\sim 12°$,
Altitude $\sim$705,000 ft. (215 km)
Velocity $\sim 40 \times 10^3$ ft/sec

The EPA selected represents the center of an estimated entry corridor bounded by limits of $\sim 11°$ for "skip out" and $\sim 13°$ for aerodynamic loading. The altitude indicated is the distance from the surface where the sensible atmosphere is thought to begin while the entry velocity is taken to be the periapsis velocity of the manned flyby vehicle.[6]

After entry and at a Mach number of about 1.5, parachutes are deployed for stabilization during transonic flight. After transition to the subsonic regime, the chutes are jettisoned and terminal velocity condition is achieved. The six balloon canisters are sequentially jettisoned at altitudes somewhat above their target altitudes of 45, 40, 30, 25, 10 and 5 km, respectively. A barometric sensor is used to initiate each discrete event and high drag parachutes are employed to effect a clean separation of the first four canisters from the descending probe, as well as to reduce the dynamic pressure to an acceptable 0.75 lbs/ft^2 at their target altitudes.[7]* For the two lowest altitude balloons, only small stabilization chutes are needed since a dynamic pressure environment of about 20 lbs/ft^2 is considered acceptable during inflation of a reinforced steel weave balloon. The parachute drag and increasing balloon pressure rapidly bring the balloon to full deployment. The parachute and canister containing the spent inflation system are then jettisoned. The super-pressure balloon becomes operational at its design altitude which corresponds to a particular atmospheric density. A super-pressure balloon is characterized by operation at a constant pressure slightly above ambient and at ambient temperature. This thermodynamic property results in a constant lift capability independent of ambient temperature but dependent on the difference in average molecular

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*Experience has shown that for reliable in-flight deployment of polymide balloons a dynamic pressure less than 1 lb/ft^2 is desirable.

weights of the balloon gas and the atmosphere. The estimated balloon leak rates are sufficiently low to preclude the need for gas resupply during the one month design lifetime.*

Generally, the six altitudes at which balloons are to be deployed have been chosen to provide for reasonable investigation of the low, intermediate and high altitude domains of the atmosphere. Deployment at altitudes of 5 and 10 km is suggested to cover the near surface region of the atmosphere. Specification of 25 and 30 km intermediate altitudes covers the temperate domain in which future buoyant Venus laboratories might be deployed. This region will probably lie within the cloud cover. Balloon operations at altitudes of 40 and 45 km cover that portion of the atmosphere which is thought to be close to the tropopause. The balloons are designed to operate in a model atmosphere based on the Soviet Venus-4 mission data and brightness temperature data obtained from earth-based observations. The model represents a thermodynamic estimate of the atmosphere on the sunlit side of Venus approximately 30 degrees in longitude from the terminator. Table I lists the model pressures and temperatures at the six balloon altitudes.

TABLE I: Estimated Values of Temperature and Pressure at the Six Balloon Altitudes**

Altitude (km)	Temperature (°K)	Pressure (bar)
5	663	14.5
10	625	10.0
25	500	2.5
30	465	1.4
40	385	0.3
45	340	0.1

*A nominal balloon lifetime of one month is considered to be a reasonable compromise between desired experiment time and thermal control subsystem weight.

**The values presented in Table I have been estimated for the illuminated side of Venus. The sources of information used were i) the Venera 4 measurements extrapolated to 45 km altitude, and ii) measurements of the phase variation of microwave brightness temperature.[8]

In the mission concept two probes would be employed to deliver a total of 12 balloons to the atmosphere during each of the two Venus encounters. As an example of a tentative probe targeting scheme, Figure 2 shows the target areas and tracking satellite orbit for the first encounter, as viewed from the approaching manned vehicle. For a given approach trajectory the entry corridor constrains the locus of permissible target areas to a band about 12 degrees from the limb. An important consideration in the selection of the target areas shown was the desirability of acquiring data from both sides of the terminator while avoiding the sub-solar region which is expected to be excessively hot. Thus the chosen areas lie near the terminator about 12 degrees from the limbs, separated by 156 degrees of central angle.

Since for tracking and data acquisition the targets must be near the orbiter ground track, a high inclination orbit is required. A 4000 km altitude circular orbit provides ~4800 km of balloon tracking and communication cross track coverage for the assumed antenna subsystem on the orbiter. During every 3 hour orbit, each balloon is located using a combination of range, range-rate and angular measurements and its stored environmental data is transmitted to the orbiter for subsequent relay to Earth. Assuming a minimum of three locations of the same balloon to be necessary for a rough determination of gross circulation patterns, the specified orbital altitude would accommodate a maximum average cross track wind velocity of between 270 and 400 km/hr.

A surface spatial accuracy of location of the balloons of some tens of kilometers is expected to be obtainable and would be adequate for circulation studies.[9] Knowledge of balloon altitude is required for accurate location and also for data analysis. The altitude of a balloon may be determined given the measured values of ambient temperature and pressure providing the temperature lapse rate and the surface pressure are known. A drop-sonde probe carried on this mission measures the atmospheric parameters required.[10]

Although somewhat arbitrary at this time, the targeting strategy adopted allows the acquisition of atmospheric information from two widely separated regions of the planet. Precursory data from unmanned reconnaissance orbiters and atmospheric probes should provide more definitive targeting guidelines in the future.

III. PAYLOAD SUBSYSTEM

The payload subsystem carried by each of the meteorological balloons will include a pressure gauge, three mutually orthogonal accelerometers, a sferics detector, a humidity gauge, and a thermistor for ambient temperature measurement. Table II presents the estimated weights, power requirements and data return for the payload subsystem.

TABLE II - PAYLOAD INSTRUMENTATION

Instrument	Weight (ounces)	Power (mw)	Data (bits/orbit)
Omni-Accelerometer	16	540	420
Sferics Detector	24	54	110
Static Pressure Transducer	5	150	85
Thermistor	3	5	85
Humidity Detector	3	5	85
	51 ozs	754 mw	785 bits
	or 3.2 lbs		

Total data obtained assuming all balloons remain operational and within orbiter antenna coverage for full 30 day design lifetimes, $\sim 2.3 \times 10^6$ bits.

The accelerometers measure the gross effects upon the balloon motion of any wind gusts and turbulence. To reduce power dissipation and the associated thermal control requirement, the accelerometers sample every 15 minutes for 3 minute durations. During each sampling period, a record is made of the number of occasions upon which the vector sum of the three accelerations exceeds a preset threshold and also of the length of time for which this occurred. The complete record will, in addition, contain the maximum acceleration experienced in each of the three directions during the data collection period. This sampling mode results in the acquisition of about 35 bits of data per sampling period, for a total of 420 bits every 3 hours.

Data from the thermistor and pressure gauge are used for altitude determination and in addition allow the spatial variation of temperature and pressure to be mapped. Suitable ceramic thermistor devices in the form of beads and thin wires for the accurate measurement of ambient temperature are readily obtainable. As each super-pressure balloon floats in the atmosphere at a known constant density, measurement of temperature allows the ambient pressure to be calculated. However, since the redundancy of separate pressure measurement is associated with only a small weight penalty it is considered appropriate to make this measurement as a means of checking the temperature record. Within the range of pressures expected up to an altitude of 45 km the performance of state-of-the-art aneroid gauges will be quite adequate. Pressure and temperature are simultaneously measured once every 15 minutes providing about 170 bits of data in a 3 hour period.

The sferics detector enables observations to be made of the general electrical activity of the atmosphere. The detector consists of a small whip antenna and a broad-band radio receiver. It operates continuously counting the total number of electrical discharges detected during each 15 minute interval. This data acquisition mode produces about 110 bits in 3 hours. From the analysis of this information, a general picture of the electrical activity of the Venus atmosphere should be obtained, and it may be possible to detect any correlation between such activity and position on the planet.

Water vapor is a very important atmospheric constituent because of its transmission properties in the I.R. and the latent heat released if condensation occurs. Direct spectroscopic observations have shown that water vapor exists above the clouds covering Venus. The Venus-4 sensors detected water vapor in the lower atmosphere and there is a possibility that the clouds themselves may be composed of ice crystals. It is therefore considered desirable to equip the balloons with humidity detectors to determine the spatial variation of water vapor concentration. Such a detector, consisting of an electrically conducting chemical film, registers changes in humidity by its change in resistivity. The humidity measurement is performed simultaneously with pressure and temperature sampling. Humidity data acquisition over a period of 3 hours provides about 85 bits of information.

During each three hour orbiter revolution, each balloon acquires, stores, and transmits to the orbiter about 785 bits of atmospheric data. Thus, the total data obtained from the meteorological balloon system on every orbit is about 9450 bits. In the event the balloons remain operational and within orbiter antenna coverage for their design lifetimes, the total amount of atmospheric data acquired would be about 2.3×10^6 bits.

IV. SUBSYSTEMS

The subsystems composing the meteorological balloon system are briefly discussed in terms of their conceptual design and operation. The primary objective is to determine reasonable subsystem weight estimates which in aggregate provide an estimate of the total system weight at separation from the manned vehicle. A secondary objective is to develop a preliminary subsystems operations concept. The subsystems discussion is divided into two categories, Balloon Subsystems and Deployment and Delivery Subsystems.

Table III SUBSYSTEMS WEIGHT SUMMARY

Subsystems	Balloon Altitudes (KM)						
	5	10	25	30	40	45	
Payload Instrumentation	3						
Data Handling	2						
Communications	13		10				
Power Supply	9						
Thermal Control	51	37	15	11	7	6	
Structure	7	6	5	5	4	4	
Balloon	38	37	5	5	7	13	
Deployed Weight	123	107	49	45	42	47	
Gas Supply	60	46	25	26	21	24	
Parachute	2	2	3	3	3	3	
Deployment Container	5	4	3	3	2	2	
Jettisoned Weights	190	159	80	77	68	76	650
						Delivery Subsystems	1152
						Launch Weight	1802

NOTE: All weights in pounds

A. Balloon Subsystems

Each meteorological balloon has the following subsystems:

1. Instrument payload
2. Data handling
3. Communications
4. Power supply
5. Thermal control
6. Structure
7. Balloon

The design approach adopted was to make all balloons derivatives of the lowest altitude balloon. Table III includes the total weight of each of the subsystems as a function of balloon altitude. Figure 3 presents a preliminary layout of a deployed balloon as well as pertinent balloon material and dimensional data as a function of flotation altitude.

The weights of subsystems 2) and 4) are independent of flotation altitude and are therefore the same for each balloon. Subsystem 3) is slightly heavier for the two lowest altitude balloons than for the other balloons. The weights of subsystems 5) through 7) are strongly dependent on altitude and thus differ significantly for each balloon. Each of the subsystems is briefly discussed below.

1.0 Instrument Payload (see Section III)

2.0 Data Handling

The output of the payload sensors is digitized by the analog-digital (A/D) conversion equipment, electronically processed and sent to the magnetic switch memory. The weight estimate for the A/D equipment and electronics is 1.5 lbs.[11] A magnetic switch memory with a storage capacity of about 2×10^4 bits, weighing approximately 0.5 lbs, is selected to cover the data storage requirement.[12] In terms of capacity this design is conservative since for nominal balloon operations the maximum storage requirement is only 785 bits. The total subsystem weight is therefore about 2 lbs while the power consumption for these equipments is estimated to be one watt.

3.0 Communications

This subsystem is divided into two functional sections: 1) beacon acquisition, and 2) ranging and data transmission. Each section uses a different transmitter but shares a common antenna, preamplifier and receiver.

The orbiter transmits a fixed frequency interrogation carrier in a cross track fan beam configuration which has a 27 degree half angle. Carrier transmission is performed on a periodic 84 percent duty cycle whose period is one second. The balloon preamplifier and receiver which must be on for reception of the interrogation signal operate on a periodic 17 percent duty cycle of 1 second period. Using this scheme, an orbiter-balloon link is in principle guaranteed for every potential acquisition opportunity without excessively burdening the power supply subsystems. The beacon acquisition transmitter on each balloon accepts the amplified interrogation signal from the receiver and immediately transmits an identification carrier of predetermined frequency. When the orbiter receives the carrier, the search fan is collapsed to a pencil beam focused on the balloon. The balloon is them commanded by the orbiter to turn on the ranging and data transmitter and to turn off the beacon acquisition transmitter. The 785 bits of data contained in the magnetic switch memory are transmitted to the orbiter at a rate of approximately 60 bps resulting in storage depletion in about 15 seconds. During this period the orbiter continuously transmits a binary digital ranging signal which is turned around at the balloon and received by the orbiter multiplexed with the data. The phase lag of the ranging signal in combination with the known subsystem time delay provides continuous range and range-rate measurement over the data transmission period.

Due to the time delay between orbiter transmission of the interrogation signal and reception of the balloon identification carrier, it is possible to activate the beacon acquisition transmitters of two or more balloons simultaneously. This would occur if the balloons were lying approximately on a line normal to the ground track, each receiving the interrogation signal within the time delay period. The orbiter receives data from and ranges to the balloon whose identification carrier is received first, leaving the other activited beacon transmitters in a continuous operation mode. Therefore, each of the beacon transmitters is automatically turned off 5 seconds after activation to prevent long term continuous operation. After the first balloon is tracked and interrogated, the pencil beam expands to the cross track fan configuration and the procedure is sequentially repeated for each balloon in the antenna pattern. Since there is a possibility of reacquiring a previously interrogated balloon, a simple balloon selection logic is carried on-board the orbiter. The logic merely disables orbiter reception of a previously received identification carrier for about 10 minutes, which is ample time for the interrogated balloons to pass out of the pattern.

The helicone antenna which weighs about 2 lbs is constructed of copper tubing shaped into a conical helix with a 50° half angle providing a 1 db gain.[13] Due to the RF opacity of steel weave material the antenna is mounted on the top of the lowest altitude balloons. The estimated weight of the cables connecting the antenna to the remainder of the subsystem is 3 lbs. The cables are located in the balloon interior and are fastened to the subsystems compartment electrical bus which is located on the portion of the berillium shell surface inside the balloon. Thus the antenna system weight for the two lowest altitude balloons is about 5 lbs. Since all other balloons are RF transparent, the helicone antenna is mounted directly on top of the subsystems compartment. The antenna system weight is 2 lbs.

The solid state S-band preamplifier is an off-the-shelf item which weighs about 0.5 lbs, provides a minimum gain of 20 db and consumes 225 mw of power.*[14] This device, residing in the temperature controlled subsystems compartment, provides an amplified receiver input signal and, therefore, must be on at the time of carrier reception. The receiver, which operates with the same duty cycle as the preamplifier, consumes about 50 mw of power and weighs approximately 0.5 lbs. The estimated weight and power consumption for the beacon transmitter are 1 lb and 320 mw, respectively. The estimates for the ranging and data transmitter are 1 lb and 200 mw, respectively.[11, 13]

An additional 5 lbs is allocated for packaging and miscellaneous wiring and electronics, resulting in a total subsystem weight for the two lowest and four highest altitude balloons of 13 lbs and 10 lbs, respectively. The difference in weights is due solely to the cables required in the two lowest altitude balloons.

4.0 Power Supply

The power profile generated by the intermittent demands of subsystems (1) through (3) is equivalent to an average power load of about 0.4 watts. A 30 day design lifetime with an additional 15 percent margin of safety establishes an electrical energy requirement of 332 watt-hours. Silver-zinc storage batteries with an energy density of $46 \frac{\text{watt-hours}}{\text{lb}}$ are selected for this application.[15] Battery weight is about 7 lbs under the assumption of a 100 percent discharge capability. An additional 2 lbs is allocated for wiring, voltage regulation equipment, etc., resulting in a total subsystem weight estimate of 9 lbs.

5.0 Thermal Control

As illustrated in Figure 3 this subsystem is composed of a concentric ice water reservoir with spherical external and internal boundaries consisting of an evacuated super insulation thermal barrier

Defense Electronics Inc., Model TPA 70, S-band preamplifier and the subsystems compartment wall, respectively. At balloon deployment the reservoir is assumed to be completely frozen. Heat transfer across the boundaries of the reservoir gradually melts the ice and increases the temperature of the water to a value somewhat less than 70°C at the end of the balloon design lifetime. If a more severe thermal environment than anticipated is encountered the balloon lifetime will be reduced. Heat transfer across the internal boundary is assumed constant and equal to the average power load of 0.4 watts. Since atmospheric temperature decreases with increasing altitude there will be less heat transfer across the external wall of the reservoir for the higher altitude balloons. This results in a wide variation in estimated subsystem weight from the lowest to highest altitude balloon.

Determination of the amount of water needed for each balloon first requires knowledge of the radius of the internal reservoir boundary and the effective thermal conductivity of the external boundary. The subsystem compartment volume estimate of 310 inch^3 for all balloons is composed of approximately 270 inch^3 for subsystems (1) through (4) and 40 inch^3 of additional space allocated for miscellaneous bracketry, wiring, etc. The 4.2 inch radius of the spherical subsystems compartment is directly calculated from the known volume. The effective thermal conductivity of the external boundary is a function of atmospheric temperature and varies from about 1.1×10^{-5} B/hr-inch-R° for the lowest altitude balloon to $.4 \times 10^{-5}$ B/hr-inch-R° for the highest altitude balloon. The low conductivities are achieved through the use of a .4 inch thickness of multilayer superinsulation residing in the evacuated .5 inch space between the two outermost spherical shells. The superinsulation material is 60 layers of aluminized polymide film and tissuglas with a bulk density of 4.51×10^{-3} lbs/inch^3.[14]

Using these data, the design lifetime and various constants describing the coolant, or amount of water required for each of the balloons, is determined by the energy balance between the heat transfer across the reservoir boundaries and the two dissipative mechanisms: 1) change of state from ice to water and 2) increase in water temperature to 70°C. The mathematical expression of the energy balance gives rise to a cubic equation in the radius of the external reservoir boundary. Solution of the equation uniquely determines the volume of the reservoir and thus the weight of water needed. Also obtained is a determination of the required weight of superinsulation material,

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*The upper temperature limit of 70°C represents the approximate allowable environmental temperature for reliable preamplifier operation. It is estimated that all other system elements will function normally at higher temperatures.

thus providing the total subsystem weight estimate. The design procedure is the same for each of the balloons. The subsystem weight estimate is given for each balloon in Table III.

6. Structure

This subsystem provides the basic structural vehicle in which subsystems 1) through 5) reside. It consists of three spherical concentric beryllium shells separated and held firmly in place by several low thermal conductivity structural spacers. Miscellaneous beryllium flanges, brackets and fixtures are also considered part of the subsystem.

The subsystems compartment is the smallest of the three spherical shells with a diameter of 8.4 inches for all balloons. The diameters of the two outermost shells are uniquely determined by the required reservoir size which depends on the atmospheric temperature at the balloon altitude. A table giving the outermost shell diameter (P) as a function of altitude appears in Figure 3. Since shell buckling is the governing structural failure mode, beryllium is selected for its superior stiffness and strength at high temperature as well as its light weight characteristic.[17] In determining shell thicknesses required to withstand buckling the loading assumed on the outermost shell is the atmospheric pressure arbitrarily increased by 20 percent to provide a margin of safety.[18] The same loading is conservatively assumed to act on the two interior shells. The resulting shell weights are increased somewhat to provide for additional shell thickness in areas of stress concentration at spacer locations. Furthermore, to avoid potential manufacturing difficulties associated with very thin gauge materials the minimum allowable shell thickness is arbitrarily fixed at 0.03 inches.

The spacers, constructed of beryllium and teflon, have an estimated total weight of no more than 0.5 lbs. An additional 2 lbs is allocated for various beryllium flanges, brackets and fixtures. The total subsystem weight for each of the balloons is given in Table III.

7. Balloon

Each hydrogen filled balloon provides the buoyancy necessary to hydrostatically support all subsystems at the design altitude. The super-pressure balloon maintains a pressure slightly above ambient and its hydrostatic lift remains constant regardless of variations in the thermal environment. Estimated leak rates are sufficiently low to preclude the need for gas resupply to achieve a one month lifetime.

Using the principles of hydrostatics and assuming a spherical balloon it is possible to write a cubic equation for the unique determination of balloon diameter. This technique requires input values for atmospheric and hydrogen densities, the total weight of subsystems (1) through (6) and the area density of the balloon wall material. Balloon diameters (d) and wall materials are given in a summary table appearing in Figure 3. The material used in the two lowest altitude balloons is a silicon polymer-filled steel weave with an area density of 0.21 lbs/ft^2 capable of operating in a 1200 °F environment. A 1 mil thick double laminate of Kapton polymide film weighing 0.0092 lbs/ft^2 capable of operating at 500 °F is used in the two intermediate altitude balloons. The two remaining balloons use a 1 mil thick double Mylar laminate weighing .0074 lbs/ft^2 with operational capability to 250 °F.[7]

The calculated diameter is used to compute balloon surface area which in combination with density allows determination of total wall material weight. Total hydrogen weight required is uniquely determined from the computed balloon volume and the input value for hydrogen density. The summation of these two items is the total subsystem weight which is given for each balloon in Table III. Also appearing in Table III is the total deployed weight of each balloon which is the summation of the total weights of subsystems 1) through 7).

B. Deployment and Delivery Subsystems

These subsystems are covered in two general categories as listed below:

Deployment Subsystems:

a. Deployment container
b. Hydrogen gas supply
c. Parachute

Delivery Subsystems:

d. Entry shell
e. Structure
f. Telecommunications
g. Attitude control
h. Instrumentation
i. Power Supply
j. Thermal control
k. Propulsion
l. Sterilization canister

The estimated weight of each of the deployment subsystems is different for each balloon and is given in Table III. Also appearing in the table is the jettisoned weight of each balloon system, the total jettisoned weight, total delivery subsystems weight and the resulting probe launch weight. The weight of each of the delivery subsystems is given in Table IV while the general arrangement of the probe is presented in Figure 4.

TABLE IV. - DELIVERY SUBSYSTEMS

Subsystems	Weight (lbs)
Entry Shell	550
Structure	35
Telecommunications	29
Attitude Control	27
Instrumentation	20
Power Supply	17
Thermal Control	Negligible
Propulsion	121
Sterilization Canister	353
Total Delivery Subsystems	1152

a. Deployment Container

Each container is of a truncated conic shape with the bottom side closed. Its envelope is of sufficient size to enclose the outermost beryllium shell, the deflated balloon packaged in an open ended nylon sleeve, the hydrogen supply, and the stowed parachute. As illustrated in Figure 4 the six containers are placed in a column stacking arrangement with the lowest and highest altitude balloon systems at the bottom and top of the stack, respectively. This configuration is most suitable for sequential jettisoning of the containers during the probe terminal velocity phase shown in Figure 1B. The containers and their parachutes are pyrotechnically separated from the stack and the balloons are immediately inflated under the restraining influence of the open ended nylon sleeve. This inflation technique provides both stability and reliability for the balloon deployment from the canister. The time elapsed from canister jettison to full inflation should be no more than 5 minutes.

The maximum axial loading experienced by the column, and therefore the containers, is the approximate peak deceleration of 80 g's during entry. The containers are designed to withstand this loading with a safety factor of three, being constructed of stiffened titanium sheet (yield stress $= 168 \times 10^3$ psi) with an effective thickness which increases for container locations closer to the bottom of the stack.[19] This is reflected in Table III by the larger container weights for the lower altitude balloons.

b. Hydrogen Gas Supply

The hydrogen for each balloon is stored at 4500 psi in a toroidal tank which is located at the bottom of the deployment container. The gas supply subsystem growth factor of 11 includes the weight of necessary plumbing and assumes the use of a high strength light weight boron filament wound storage tank.[7] The gas supply subsystem weights given in Table III are directly determined from the growth factor and the required quantities of hydrogen.

c. Parachutes

The parachutes for the four highest altitude balloons are of the "solid flat" type which has a minimum characteristic drag coefficient of 0.7. The plan view parachute diameters that appear in the table given in Figure 1B are sized to produce a dynamic pressure of 0.75 lbs/ft^2 during balloon inflation. This conservatism is exercised in view of the uncertainties involved in the in-flight inflation of Mylar and Kapton polymide balloons while subject to a dynamic pressure environment more severe than 1 lb/ft^2. The parachute weights given in Table III are determined directly from the calculated diameters and increased by 30 percent to allow for the pilot chute, bridle lines, risers, etc.[19]

Since the two lowest altitude balloons are constructed of a tough polymer filled steel weave material, a considerably more severe dynamic pressure environment during inflation is tolerable. Thus, these two balloons use small light weight parachutes designed to produce stability rather than aerodynamic drag.

d. Entry Shell

The 30° half-angle sphere-cone shell is constructed of aluminum overlayed with a phenolic nylon ablative heat shield which is conservatively designed to accommodate a vertical entry into the Venusian atmosphere at about 40,000 ft/sec. The payload-to-entry weight ratio is about 0.85 resulting in an entry shell weight of approximately 550 lbs.[20] This includes a small allocation for the transonic stabilization chutes which are deployed after entry at a Mach number of about 1.5. The chutes are jettisoned immediately after passage through the transonic flight regime.

e. Structure

The structure consists primarily of a stiffened titanium conical shell whose only appreciable loading is the axial compressive force due to propulsion system thrusting. Assuming 1000 lbs of thrust and designing the shell to a buckling criterion results in a total weight of about 30 lbs.[18] An additional 5 lbs is allocated for miscellaneous brackets, fixtures and pyrotechnics resulting in a total structural weight of 35 lbs.

f. Telecommunications

The telecommunications subsystem is designed to provide a transmission data rate capability of approximately 100 bps to the manned vehicle. Since the maximum range separating the probe and manned vehicle is relatively small (less than 10^4 km), the specified data rate does not require the use of a high gain antenna or amplifier. Modeling the subsystem after that of the Lunar Orbiter with the high gain antenna and TWT amplifier eliminated and assuming a 20% reduction in weight by updating the state-of-the-art from the early sixties to the present, the resulting total subsystem weight is 29 lbs.[21] This includes two omni-antennas, a transponder, command decoder, a flight programmer and miscellaneous items.

g. Attitude Control

The cold nitrogen gas stellar inertial attitude control subsystem maintains a nominal 2° dead band attitude hold during the cruise. The sun sensor slaves the probe longitudinal axis to the sun line so that power can be produced by the solar cells while the star sensor fixes the roll attitude. Attitude control is switched to inertial reference for midcourse corrections. Conservatively designing for 10 days of dead band cruise and 5 midcourse correction maneuvers results in a nitrogen requirement of several tenths of a pound.[22] The total weight of the subsystem including the stored nitrogen and gas feed system, inertial reference unit, sun and star sensors and other miscellaneous items is estimated at 27 lbs.[21] This assumes a 20 percent weight reduction for updated state-of-the-art.

h. Instrumentation

The purpose of this subsystem is to provide monitoring capability of all probe subsystems to determine their status. It consists of various performance transducers, signal conditioning equipment, a telemetry encoder and other miscellaneous items. With the assumed 20 percent weight reduction from technology updating the total subsystem weight is estimated at 20 lbs.[21]

i. Power Supply

The solar cell storage battery power supply subsystem is designed to provide the estimated 70 watts of average continuous power required by the other subsystems. As shown in Figure 4, the 6 ft^2 of solar cell array are mounted on the exterior of the conical shell while the silver-zinc batteries are fastened to its interior surface. The estimated weights of the solar cells and batteries are 4 lbs and 3 lbs, respectively.[21, 22] Voltage regulation, charge control and boost regulation equipment, as well as some miscellaneous items, add another 10 lbs resulting in a total subsystem weight estimate of 17 lbs.

j. Thermal Control

Energy dissipated from the various subsystems is accommodated passively through provision of good thermally conductive attachment to the interior surface of the titanium shell. Slightly less than 70 watts is continuously rejected from the probe by thermal radiation to space from the exterior surface of the conical shell. The entire surface with the exception of the area occupied by solar cells and the two omni-antennas is treated to obtain the appropriate emissive characteristics.

k. Propulsion

The required total velocity change of about 750 ft/sec is provided by a hydrazine flourine propulsion subsystem with a mass fraction of 0.9 and specific impulse of 325 sec.[19] Total propellant weight of about 109 lbs consists of 99 lbs of usable propellant with the remaining 10 lbs (∿10 percent) allocated as reserves and residuals. For the 0.9 mass fraction the engine and tankage weight is about 12 lbs resulting in a total subsystem weight estimate of 121 lbs.

l. Sterilization Canister

In order to avoid biological contamination of Venus with earthly microorganisms the sterilized probe is enclosed in a sterilization canister during the trip to Venus. Immediately after separation from the manned vehicle and prior to the injection maneuver the canister is pyrotechnically jettisoned. The surface area of the canister needed to completely enclose the probe is about 294 ft^2. For canister walls of aluminum honeycomb structure with a weight density of 1.2 lbs/ ft^2 the resulting total weight is estimated at 353 lbs.

V. CONCLUSIONS

For a single Venus encounter the estimated gross weight of the meteorological balloon system at separation from the manned flyby vehicle is 3604 lbs. The system consists of two identical probes each delivering six balloons to the atmosphere. The probe weight is determined from individual subsystem conceptual designs based on existing state-of-the-art technology. Apart from the inclusion of a sterilization canister in the gross weight estimate, the influence of probe sterilization requirements has not been considered. The preliminary system operations concept is believed to be feasible.

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REFERENCES

1. Thompson, W. B., et al., "Experiment Payloads for Manned Encounter Missions to Mars and Venus," Bellcomm TR-68-710-2, February 21, 1968.

2. Smith, B. A., "Rotation of Venus: Continuing Contradictions," Science, Vol. 158, 1967, pp. 114-116.

3. Goody, R. M. and A. R. Robinson, "A Discussion of the Deep Circulation of the Atmosphere of Venus," Astrophysical Journal, Vol. 146, 1966, pp. 339-355.

4. Cutler, M. M., "Experiment Payload for Manned Venus Encounter Mission - Venus Tracking and Data Orbiter," Bellcomm Memorandum for File, June 13, 1968.

5. Thompson, W. B., Bellcomm, Inc., Private communication.

6. Cassidy, D. E., "Unmanned Entry into the Venusian Atmosphere," Bellcomm TM-67-1013-6, July 24, 1967.

7. Cassidy, D. E.,and M. H. Skeer, "Trip Report - Balloon Design and Performance, Trip to Raven Industries for Discussions with R. Anderson, J. Margenthau, and K. Quanbeck," Bellcomm Memorandum for File, June 12, 1967.

8. Barrett, A. H. and D. H. Staelin, "Radio Observation of Venus and the Interpretation," Space Science Reviews, Vol. 3, 1964, pp. 110-135.

9. Briggs, G. A., "The Location by Satellite of Meteorological Balloons in the Atmosphere of Venus," Bellcomm Memorandum for File, July 29, 1968.

10. Kostoff, R. N., "Drop Sonde and Photo Sinker Probes for a Manned Venus Flyby Mission," Bellcomm Memorandum for File, May 7, 1968.

11. Selden, R. L., Bellcomm, Private communication.

12. Schaenman, P. S., Bellcomm, Private communication.

13. Klein, E. J., Bellcomm, Private communication.

14. "Auxiliary Equipment Brochure, DS-190B," Defense Electronics, Inc., February 16, 1967.

References (Continued)

15. Mandel, H. J., "Recent Developments in Secondary Batteries," Electronic Components Lab., U.S. Army Electronics Command, Fort Monmouth, N. J., IECEC, September, 1966.

16. Cunnington, G. R., Jr., C. A. Zierman, A. I. Funai, A. Lindahn, "Performance of Multilayer Insulation Systems for Temperatures to 700 °K," Lockheed Missiles and Space Company, Final Report NAS 2-2441, May 1967.

17. Lyman, T., Metals Handbook - 8th Edition - Volume 1, Properties and Selection of Metals, American Society for Metals, Metals Park, Ohio, December 1961.

18. Roark, R. J., Formulas for Stress and Strain, University of Wisconsin, McGraw-Hill, 1965.

19. Koelle, H. H., Handbook of Astronautical Engineering, McGraw-Hill, New York, 1961.

20. Chandeysson, P. L., "A Venus Lander Probe for Manned Flyby Missions," Bellcomm TR-68-710-3, February 23, 1968.

21. "Agena Class Lunar Orbiter Photographic Project, Volume I, Technical Proposal," Boeing Co., October 2, 1963.

22. Thompson, W. B., et al., "Experiment Payloads for a Manned Mars Flyby Mission," Bellcomm TR-67-233-1, May 15, 1967.

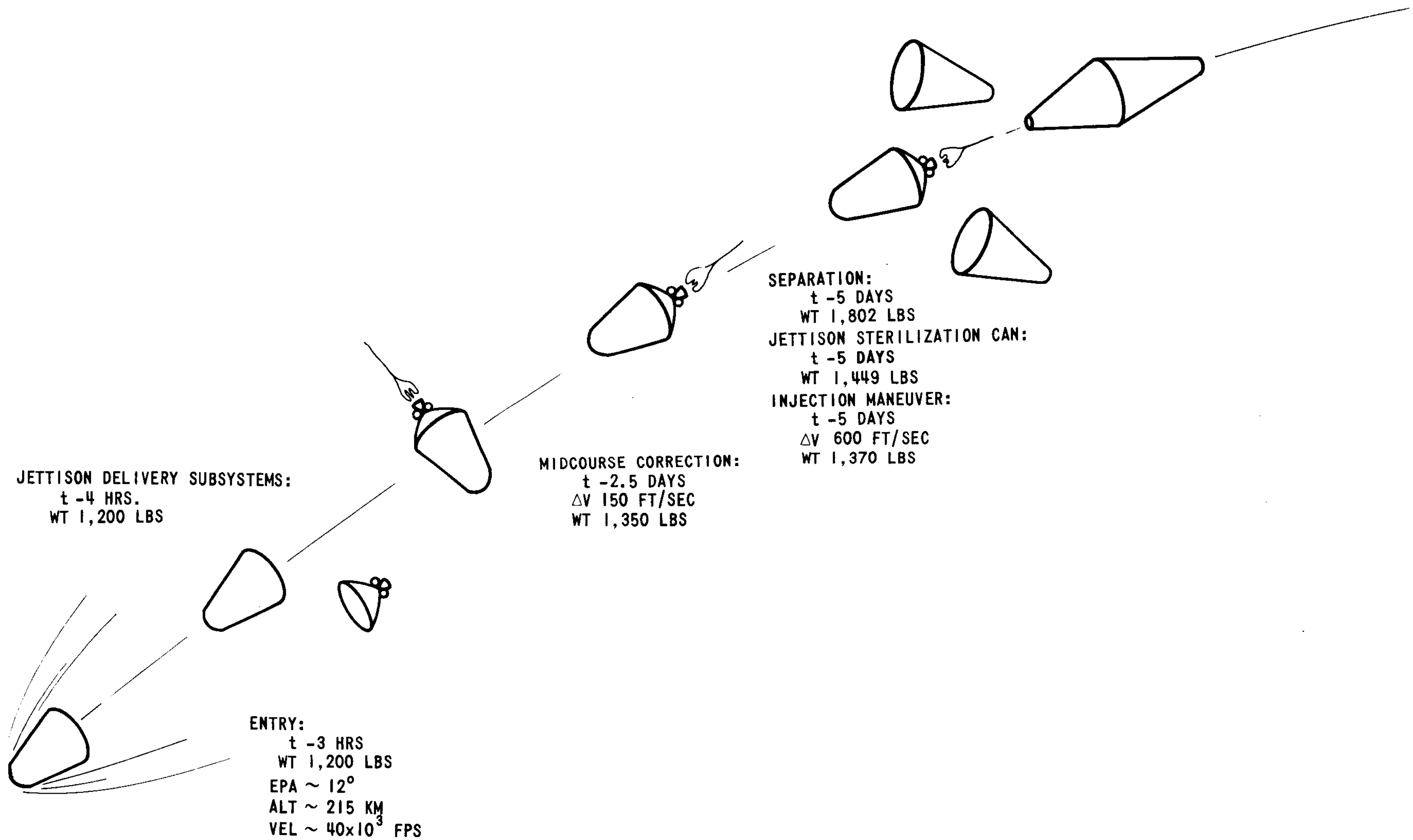
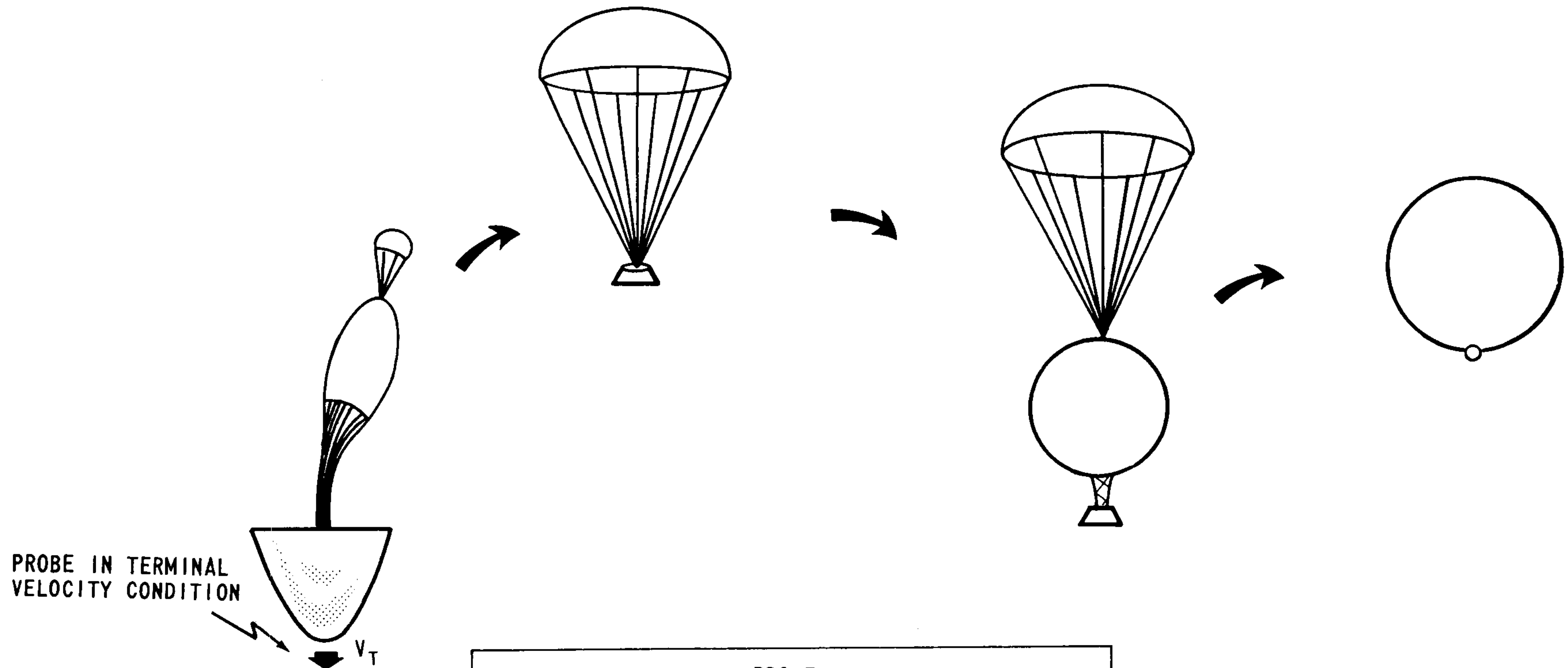


FIGURE 1A - SEPARATION TO ENTRY MISSION PROFILE



DEPLOYMENT ALTITUDE (KM)	PROBE			PARACHUTE DIAM.[1,2] (FT)
	M/C_DA (SLUGS/FT^2)	V_T (FT/SEC)	q (LB/FT^2)	
45	1.2	380	28	13.6
40	1.1	323	31	12.9
30	1.0	148	29	13.5
25	.95	118	27	14.0
10	.75	53	22	SEE NOTE 3
5	.72	43	21	SEE NOTE 3

NOTES:
1. PARACHUTE DIAMETERS ARE SIZED TO MAINTAIN $q \sim .75$ LB/FT^2 DURING "MYLAR" AND "KAPTON" BALLOON INFLATION.
2. TYPE OF PARACHUTE IS "SOLID FLAT".
3. ONLY A SMALL STABILIZATION CHUTE IS NEEDED SINCE A HIGH "q" ENVIRONMENT IS ACCEPTABLE DURING INFLATION OF A "STEEL WEAVE" BALLOON.

FIGURE 1B - TERMINAL VELOCITY BALLOON DEPLOYMENT PHASE

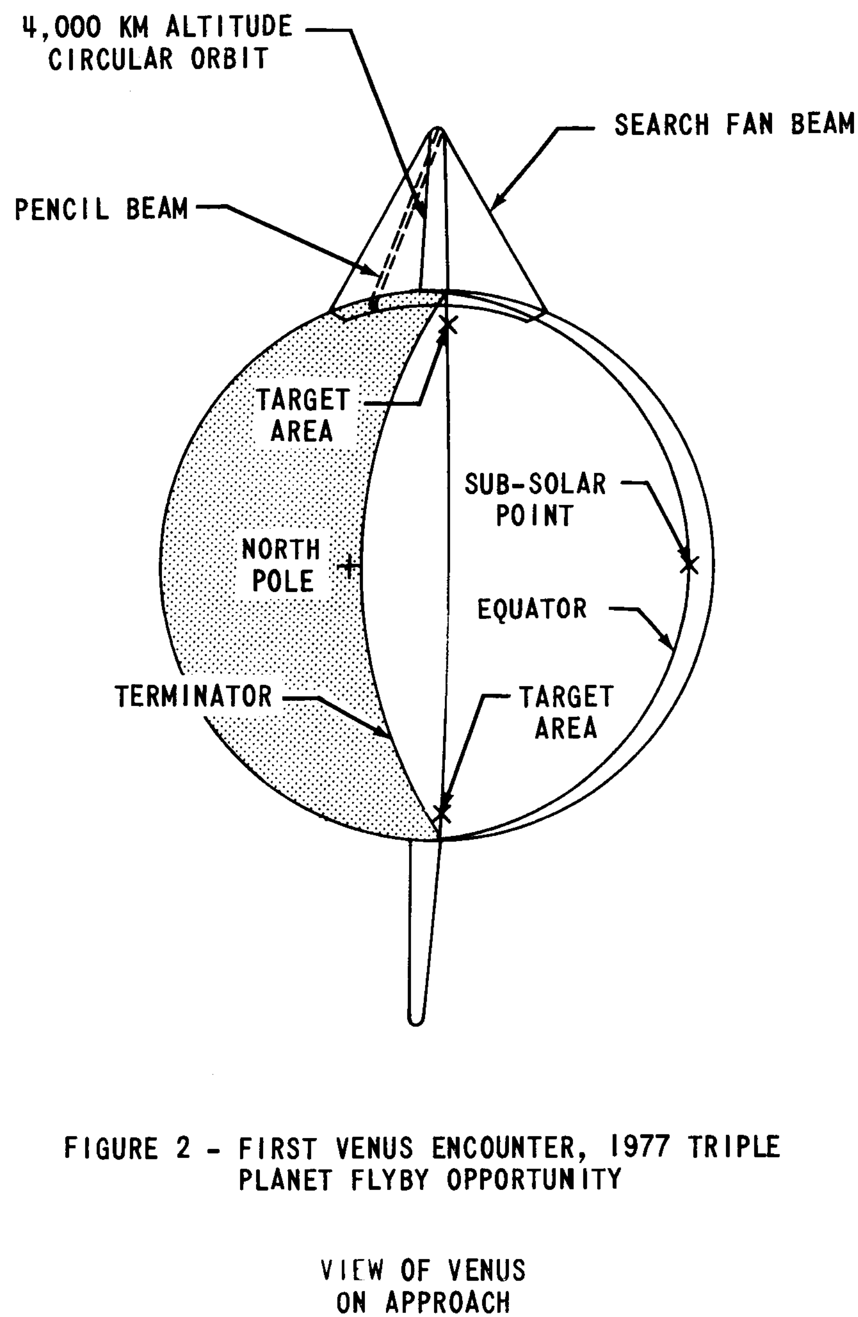
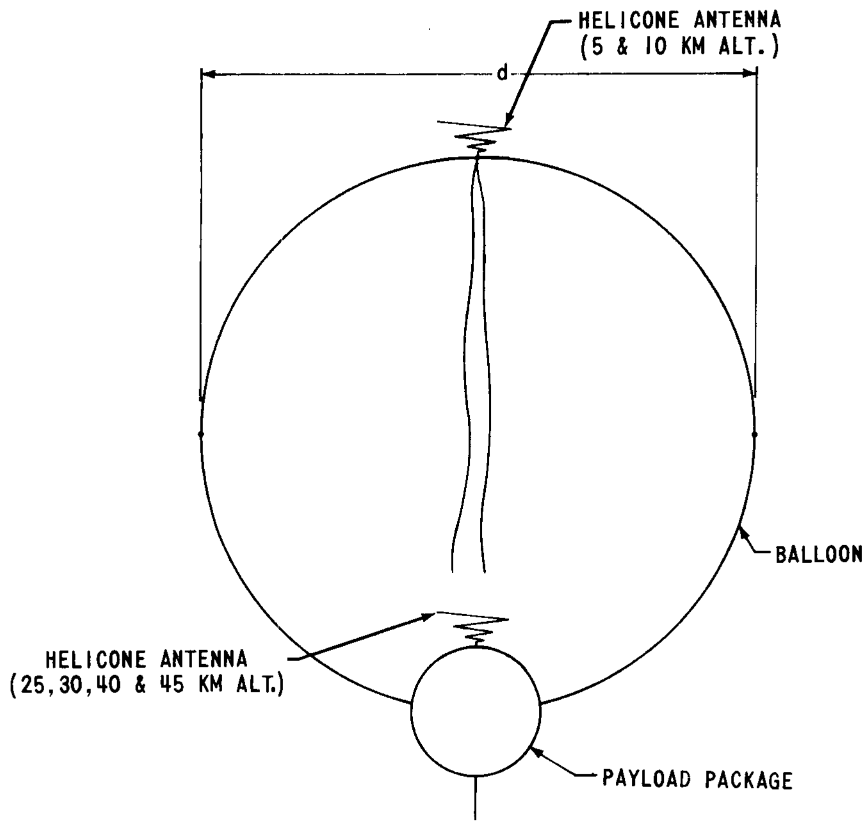
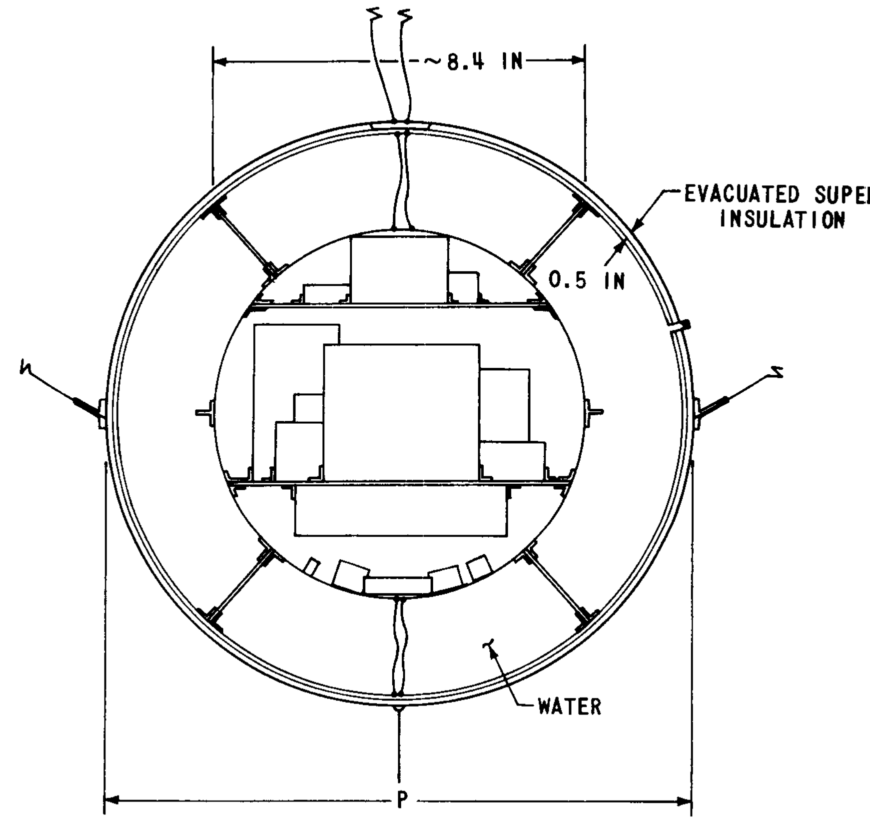


FIGURE 2 - FIRST VENUS ENCOUNTER, 1977 TRIPLE PLANET FLYBY OPPORTUNITY





PAYLOAD PACKAGE DETAIL

BALLOON ALT. (KM)	WALL MATERIAL	d(FT)	P(IN)
45	MYLAR	21.8	10.6
40	MYLAR	15.0	10.8
30	KAPTON	9.7	11.4
25	KAPTON	8.5	12.4
10	STEEL WEAVE	7.1	14.6
5	STEEL WEAVE	7.0	15.7

FIGURE 3 - DEPLOYED METEOROLOGICAL BALLOONS

GENERAL PROBE CHARACTERISTICS:

1. WEIGHT AT SEPARATION = 1,802 LBS
2. 30° SPHERE - CONE ENTRY SHELL
3. BALLISTIC COEFFICIENT: .72 (LOW ALT.) $\leq \frac{M}{C_D A} \leq$ 1.2 (HIGH ALT.)

WEIGHT SUMMARY: (LBS.)

BALLOON SYSTEM JETTISONED WEIGHTS:

45 KM ALT.	=	76
40 KM ALT.	=	68
30 KM ALT.	=	77
25 KM ALT.	=	80
10 KM ALT.	=	159
5 KM ALT.	=	190
TOTAL JETTISONED	=	650
ENTRY SHELL	=	550
PROBE AT ENTRY	=	1,200
DELIVERY SUBSYSTEMS (EXCLUDING ENTRY SHELL)	=	602
PROBE AT SEPARATION	=	1,802

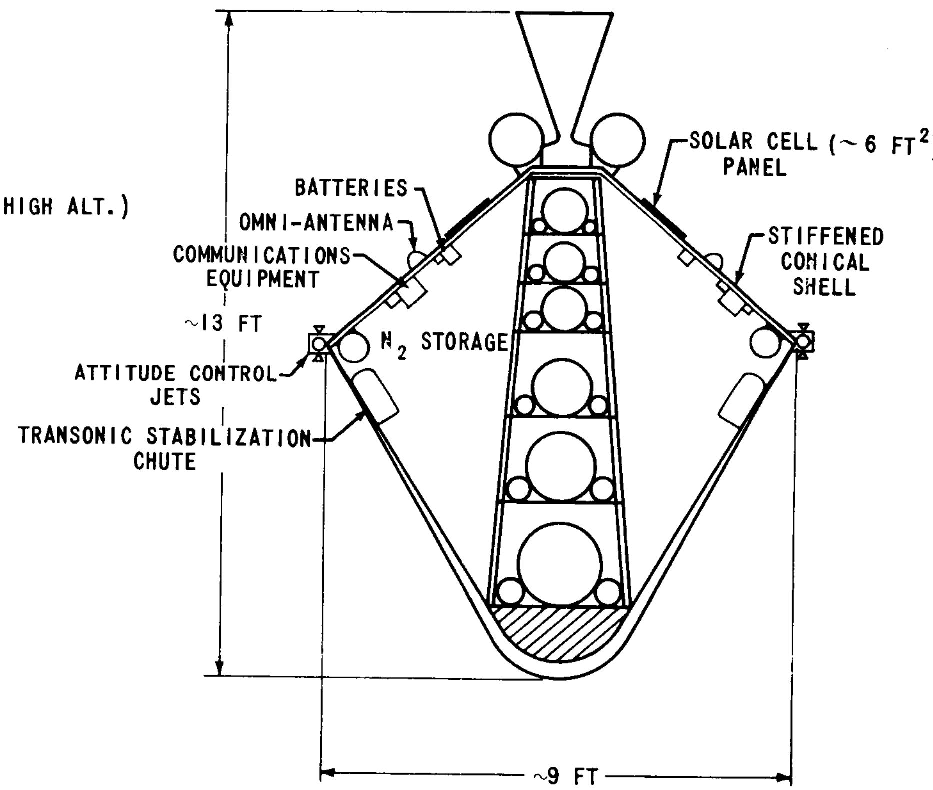


FIGURE 4 - METEOROLOGICAL BALLOON PROBE - GENERAL ARRANGEMENT